

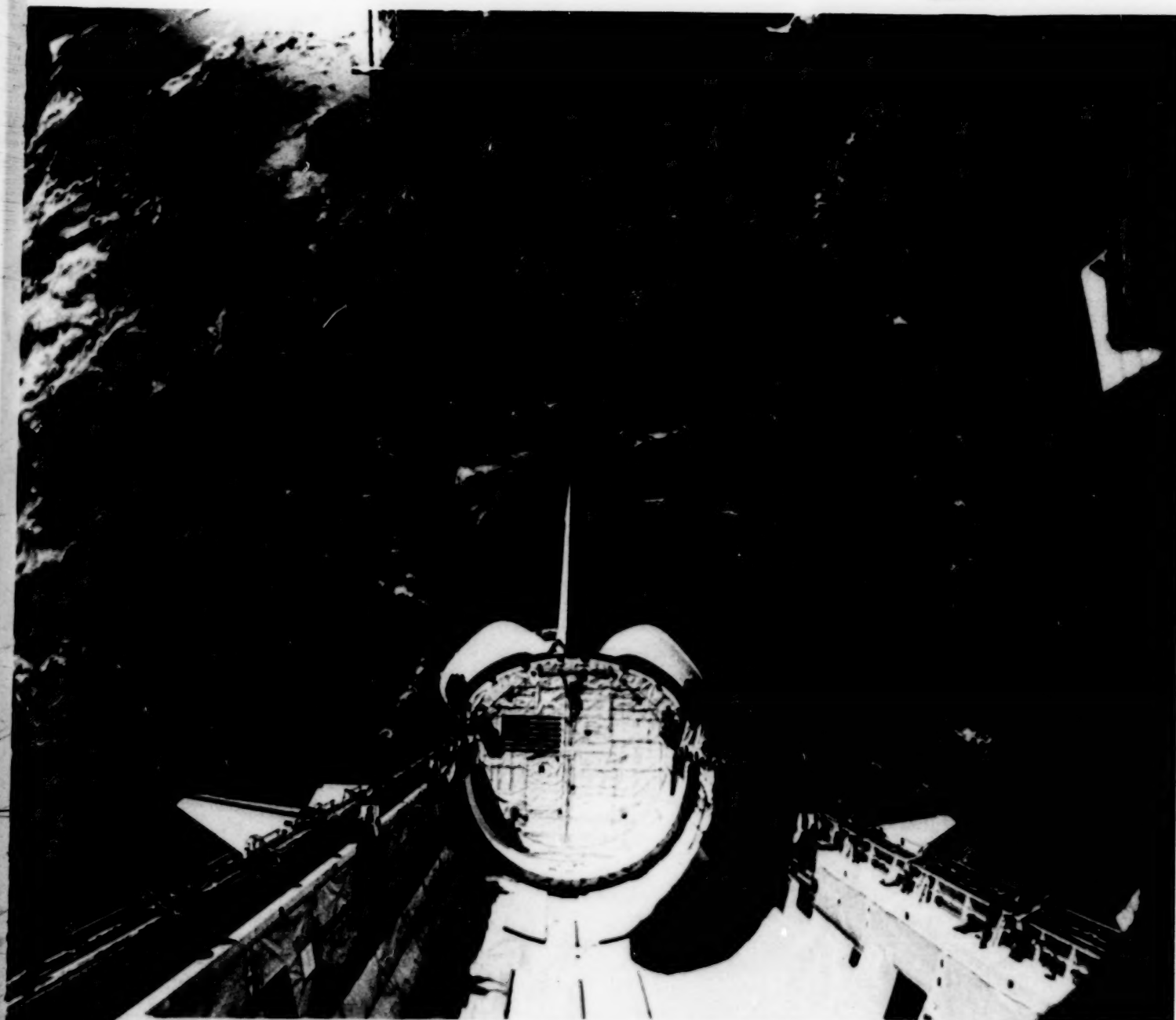
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69 Months in Space:

*A History of the First LDEF
(Long Duration Exposure Facility)*

ORIGINAL PAGE
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(NASA-NP-149) SIXTY-NINE MONTHS IN SPACE: A
HISTORY OF THE FIRST LDEF (LONG DURATION
EXPOSURE FACILITY) (NASA) 15 p CSCL 22B

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hen Space Shuttle *Challenger* placed the Long Duration Exposure Facility (LDEF) into orbit on April 7, 1984, the space age was already over a quarter-century old. Satellites had proliferated in number and purpose, men and women had lived and worked in space, manned missions had visited the Moon, and unmanned missions had ventured far into the solar system. By 1984, the Shuttle was beginning to change the character of space operations, and new national goals for space were being defined. This was the context for the flight of LDEF.

Fifty-seven space experiments, self-contained in 86 desktop-sized, open trays, were arrayed checkerboard-style around the surface of LDEF. These experiment trays faced outward from both ends and all 12 sides of the 11-ton, 30-foot-long, nearly cylindrical satellite.

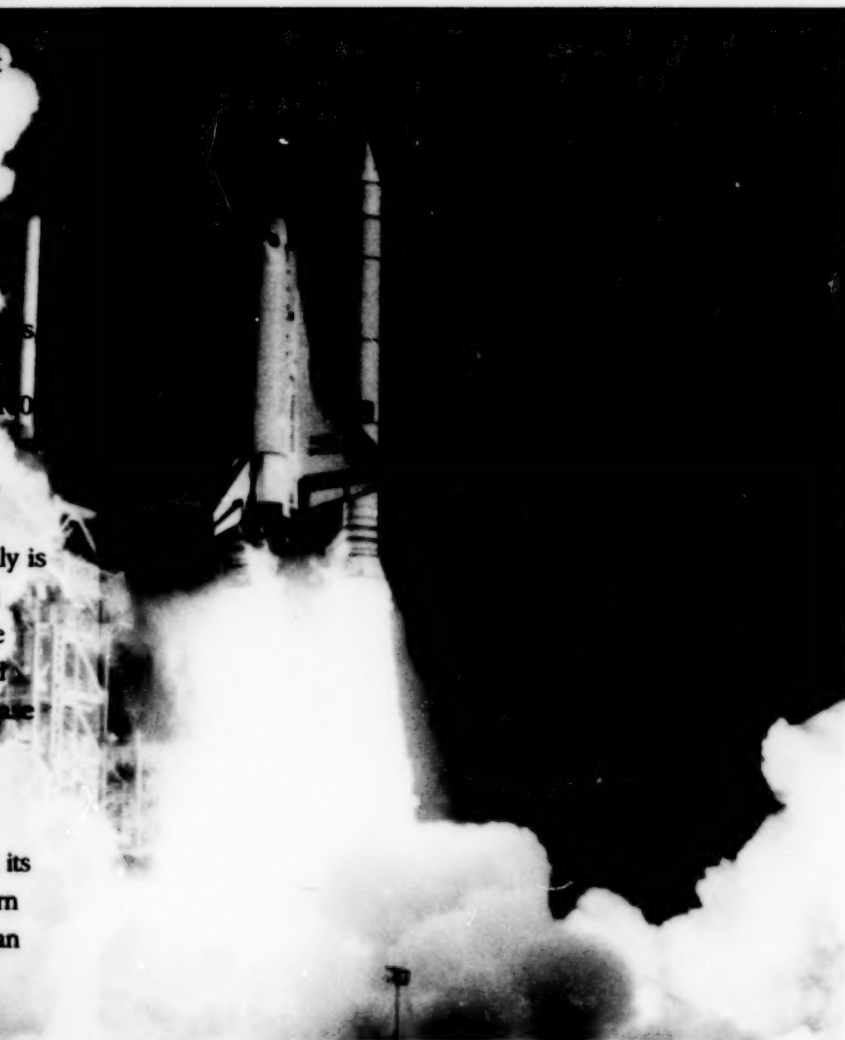
The experiments carried more than 10,000 specimens to gather scientific data and to test the effects of long-term space exposure on spacecraft materials, components, and systems. Results will be invaluable for the design of future spacecraft such as Space Station *Freedom*.

In January 1990, Shuttle *Columbia* retrieved the orbiting LDEF and its unprecedented cargo of nearly 6 years worth of priceless data. More than 200 LDEF experiment principal investigators (representing 33 private companies, 21 universities, 7 NASA centers, 9 Department of Defense laboratories, and 8 foreign countries) and over 100 Special Investigation Group (SIG) members are now intensively conducting post-flight analyses.

LDEF signifies a step toward the future. Not only is it a low-investment, high-return way to take full advantage of the new capabilities offered by the Shuttle, but also its mission (still in progress and going quite well) is to enlarge the knowledge base for future advances in space science and technology.

This booklet summarizes the LDEF project from its conception, through its deployment, to the return of the experiments. The booklet also includes an LDEF chronology and a fact sheet.

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**Early LDEF
Concept**

Although LDEF ultimately accommodated a broad range of scientific and technological interests, including measurements of the meteoroid environment in space, it was first conceived solely as a Meteoroid and Exposure Module (MEM). NASA Langley Research Center in Hampton, Virginia, proposed MEM in 1970 as the first Shuttle payload.

The need for information about the meteoroid environment in space is as old as spaceflight itself; in fact, micrometeoroids had been an object of study as early as 1959 in the Vanguard experiments, America's first scientific satellite program. During the 1960's and 1970's, additional meteoroid work in space gave scientists experimentation experience that proved invaluable for LDEF.

One early method for measuring meteoroid impacts was the pressurized-cell detector, in which a sensor would read and report the loss of pressure that resulted from penetration of the space-exposed surface of the cell. Different cells had different skin thicknesses, which were pre-calibrated in ground tests to indicate different penetrating masses. Data transmission equipment relayed information about impacts and penetrations to Earth.

Another method that evolved was the capacitor detector, in which each penetration generated an electrical signal. Meteoroid researchers also studied the "bumper" concept, a shielding technique in which a thin, external sheet of material causes a penetrating object to break up and spread out as debris over a larger area, reducing the likelihood of spacecraft penetration.

These space research activities evolved largely for the benefit of spacecraft designers, who needed a clearer understanding of the hazards that meteoroids imposed. The story of MEM/LDEF is in part the story of efforts to achieve this understanding. Research techniques were also evolving for other areas of space study, and LDEF would ultimately accommodate those as well.

MEM was foreseen as a cylinder sized for the Shuttle's payload bay. The Shuttle would place it in orbit, where its large surface area would collect a comprehensive sample of meteoroid data. MEM was to include thick-skin, thin-skin, and bumper

configurations. After several months, the Shuttle would retrieve MEM and bring it to Earth for data analysis. This retrievability feature, both for MEM and for LDEF, was especially important.

In almost all previous space research, the only measurements available were those that could be transmitted to Earth. Data transmission

equipment was expensive, took precious room in a spacecraft, and was not always absolutely reliable. Retrievability eliminated the need for this equipment for the MEM or LDEF. Retrievability also placed hard experimental evidence, not just transmitted signals, into researchers' hands. This evidence allowed in-depth analysis, use of a variety of analytical equipment, and participation by an increased number of investigators.

As important as the developing field of meteoroid research was, it could not obscure the attractiveness of a retrievable, MEM-type experimentation vehicle for many other kinds of space research.

In 1974, MEM was renamed LDEF, and LDEF officially became a NASA project managed by Langley Research Center for the Office of



Astronaut Donn F. Eisele beside a mockup of LDEF's early-1970's conceptual forerunner, the Meteoroid and Exposure Module.

Aeronautics and Space Technology (now the Office of Aeronautics, Exploration and Technology). Meteoroid research was still seen as the primary mission. Eventually, however, what had begun as a concept for meteoroid research was to become a vehicle also meant for:

- studies of changes to physical properties of materials over time in the space environment,
- performance tests of spacecraft systems,
- evaluations of components used in powering spacecraft,
- experiments in the growth of crystals in low gravity, and
- scientific investigations in space physics and related fields.

By early 1990, science and technology investigators around the world would be hard at work analyzing the results.

The LDEF Spacecraft

Besides the advantages of retrievability, LDEF offers:

Simplicity. LDEF is a passive and potentially reusable spacecraft. Complex power, positioning, and data acquisition systems are not required.

Stability in flight. LDEF has been designed to use gravity to be inherently stable in orbit. Thus, a given experiment keeps a single orientation with respect to the orbit path, for example, facing ahead or facing Earth. Knowledge of an experiment's orbit orientation enhances clear understanding in post-flight data analysis because impacts and other space-environment effects are different for different orientations. This clarity is also enhanced by another result of inherent stability, the constancy of LDEF's drag as it moves through the uppermost traces of the Earth's atmosphere. LDEF's unique passive stability means that it does not need propulsion or maneuvering systems. Without the requirement of attitude control system jet firings, LDEF is virtually free of acceleration forces—a key advantage for certain experiments.

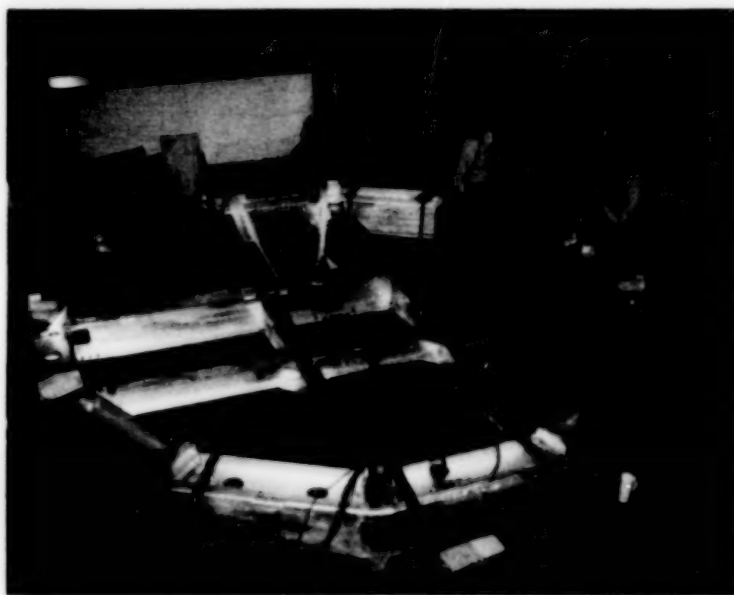
A pristine environment. The liquid and particulate contaminants associated with human presence and the firing of propulsion systems can

skew the experiments inside or near manned or maneuvering spacecraft. LDEF travels through space with no crew and no propulsion.

Relaxed space and weight limitations. In typical pre-Shuttle experiments, every ounce or cubic inch was important. LDEF experiments benefit from the Shuttle's large payload bay and tremendous lifting capacity. LDEF experiment trays provide up to about 12 cubic feet of volume, and, if necessary, LDEF can support even larger experiments in its internal structure.

The satellite that provides these advantages for space research was designed and fabricated at Langley in the late 1970's. The nearly cylindrical, mainly aluminum framework provides a grid of spaces for attaching experiment trays and carrying them exposed through the space environment.

In cross section, LDEF has the shape of a dodecagon (a 12-sided regular polygon). The



Fabricating LDEF's center ring frame

evolution from the earlier MEM cylinder concept gave LDEF its 12 flat sides as a way of accommodating simple, flat experiment trays. The dodecagonal shape is close enough to cylindrical to ensure efficient use of the Shuttle's payload bay.

At the heart of LDEF is the dodecagonal center ring frame, a comparatively heavy aluminum structure. To ensure the structural integrity of LDEF, the

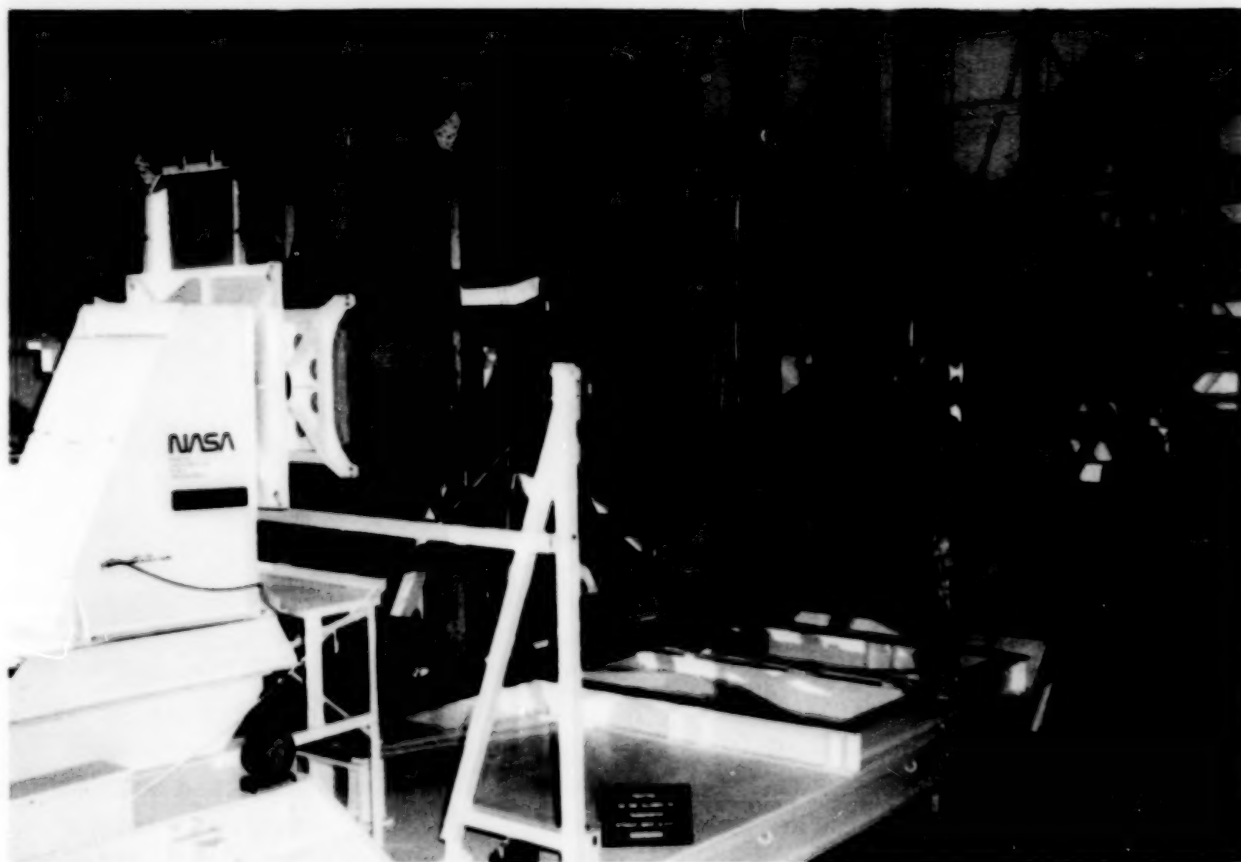
center ring frame welds had to meet extraordinarily high quality control standards. Weld quality was verified by X-rays.

Aluminum beams called longerons connect the center ring frame to the two end frames. With the addition of aluminum intercostals, which connect from longeron to longeron around the 12 sides of the satellite's circumference, the 86-tray framework was complete: 12 longitudinal rows of 6 tray spaces each, with a total of 14 additional tray spaces in the 2 end frames.

Longerons are bolted rather than welded to intercostals and to the center ring and end frames.

At the center of the space-facing end frame of LDEF is a viscous magnetic damper, a stabilizing device about half the size of a basketball. This damper uses the Earth's magnetic field and a viscous fluid to gradually cancel destabilizing vibrations caused when the Shuttle places LDEF into orbit.

The outer sphere of this damper is rigidly attached to LDEF. Floating concentrically inside it is a second sphere, separated from the outer one by a layer of silicone oil. Rigidly attached inside the inner sphere is a magnet, which tends to keep the inner sphere constantly aligned with the Earth's magnetic field. In turn, flow resistance in the oil tends to quell motions of the outer sphere, thereby



LDEF just before shipment to Kennedy Space Center

Thus, by simply replacing the longerons, a shorter or longer LDEF can be easily constructed to meet the payload manifest requirements for a given Shuttle flight.

For overall stiffness, tubular structural members stretch diagonally through the interior of LDEF, connecting the center ring frame with the end frames.

damping unwanted vibrations in LDEF.

For transport to and from orbit, LDEF rides in the Shuttle payload bay like a battery in a flashlight. Two attachment points on opposite sides of LDEF's center ring frame connect to fixtures in the Shuttle's sides to provide the main support. The third fixture attaches to the payload bay deck, and the fourth fixture, at the center of one end, connects to the

Shuttle via a special beam (called the "walking" beam) which stays with LDEF in orbit.

This attachment system appears simple but actually responds to the complexities of Shuttle operations. The in-flight loads of the 11-ton LDEF must be distributed precisely through the Shuttle structure.

The system also simplifies recovery of LDEF from orbit. Temperature extremes in space can slightly bend or warp LDEF, displacing its attachment points. To ensure a clean fit, the points are distributed about LDEF such that no more than three can touch the Shuttle in any given plane. Just as a three-legged stool can always find stability, LDEF's attachment points can always find their way smoothly into place. The ability of the "walking" beam to rotate slightly provides the needed tolerance.

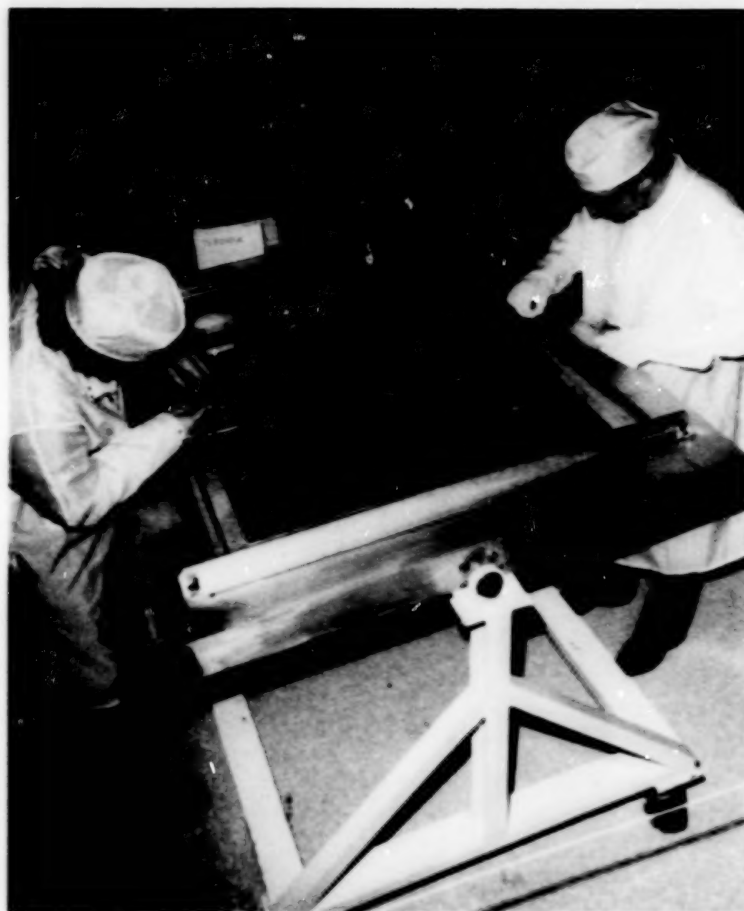
Construction of LDEF began in 1976 and was completed in August 1978. Although it had been designed to be strong enough to preclude the need for extensive structural tests, LDEF underwent flight qualification dynamic and static tests at Langley before being stored in 1979 for use in space via the Shuttle.

Experiments in Trays

Although the technological and scientific questions that LDEF addresses are complex, the LDEF approach to answering them has purposely been kept simple. The LDEF project was designed to minimize logistical, financial, and paperwork burdens on investigators and other project participants.

Such a philosophy continues the motivating spirit of the Shuttle, the space transportation system on which LDEF was predicated. The Shuttle was created to make access to space easier and simpler.

For anyone involved in LDEF, this approach was clear from the beginning. When the opportunity to place experiments aboard LDEF was formally announced to the worldwide technological and scientific community in 1976, the only application documentation required of a prospective



Investigators prepare an experiment tray for installation on LDEF

investigator was a letter of intent, a single copy of a brief proposal, and the validation of institutional support.

Later, when experiments had been chosen from among the hundreds of applications submitted, the relationship between NASA and a given experiment team was formalized in a Memorandum of Agreement that was a mere two pages long. With the viability of each chosen experiment already established, NASA thereafter held to a relationship with its LDEF experimenters similar to that of a landlord with a tenant: as long as the safety and physical integrity of LDEF and its experiments were not jeopardized, experiment teams could enjoy independence.

Independence and simplicity extended to the experiment trays as well. With trays, investigators could fully prepare their experiments at their home institutions, ship them to Kennedy Space Center (KSC) for spaceflight, and then ship them home for extensive data analysis. Special covers and

shipping containers were fabricated for handling and moving the experiment trays.

Most of the trays are slightly larger than 3 by 4 feet, with depths of 3, 6, or 12 inches. Trays for the two end surfaces on LDEF are about 2 1/2 feet square. Some experiments used more than one tray, and some used only 1/4 or 1/6 of a tray, sharing the remainder with other experiments. Each tray slips into its appointed place in the checkerboard surface pattern of LDEF and is held there by clips which are bolted to the LDEF structural framework.

Although LDEF space research was generally conceived as passive (that is, requiring no power source or data handling capability), many experiments did have modest requirements for active systems. For each experiment that needed to record measurements on tape a few times per day, LDEF used a standard Experiment Power and Data System (EPDS). EPDS, which consists of a data processor controller assembly, a magnetic tape module, and a lithium battery, was designed to offer versatility in accommodating different kinds of data collection needs.

Experiments needing protection from transient environments on the way to and from orbit used a special Experiment Exposure Control Canister. This canister is basically a sealable drawer that is opened and closed by a small electric drive system triggered by a preset timer. The canister opens after deployment into orbit, exposes its experiment to the space environment, then seals the experiment back inside before retrieval.

Studying the Space Environment

The space environment that LDEF experiments study includes radiation, vacuum, extreme temperatures, atomic oxygen, flecks of spacecraft paint, interstellar dust, micrometeoroids, the absence of gravity, etc. The purpose of such study is to enlarge the knowledge base for building future technology, especially the space technology of the next decade.

This enlarged base of knowledge can be useful in several ways. It can improve the materials and

design of spacecraft and space equipment, especially structures slated for long stays; it can tell us more about commercial or industrial opportunities in space; and it can validate or suggest modifications to procedures used on Earth to test space materials and systems, thereby increasing confidence in the easier, less expensive, Earthbound tests. For longer term use, it can add to our fundamental understanding about Earth, the nearby reaches of space, and the universe itself.

Some examples of the scientific and technological questions that LDEF experiments address follow:

- *How durable are composite materials in space?*
Composite materials (plastics reinforced with high-strength fibers such as fiberglass) are lighter and stronger than metals and are therefore attractive to spacecraft designers.
- *Which thermal coatings work best over time?*
Certain paints and other materials used as coatings can passively and effectively counteract the temperature extremes that spacecraft must endure. But radiation, atomic oxygen (individual oxygen atoms), and other space effects can degrade their effectiveness.
- *How can solar cells used in space be improved?*
Spacecraft need electricity, and solar cells can use the Sun to generate it, but only by facing the space environment with little or no protection.
- *Which heat pipe concepts work best?*
Spacecraft need temperature control. Simple, inexpensive heat pipes can passively manipulate thermal conditions by capitalizing on the natural effects of the zero-gravity environment.
- *Can fiber optic materials find wide use in space?*
If radiation and other effects do not prove to be obstacles, space systems can use the advantages of fiber optics: lightness, low requirements for power, and relative immunity to electrical disturbance and interference.

- *What potential does space hold for crystal technology, and how well do crystals hold up in space?*

Crystals are of great value for integrated circuitry and for compact data storage because they are materials with regularly repeating, internal arrangements of their atoms. Crystals are best produced in extremely low gravity over lengthy periods, which are test conditions offered only by LDEF.

- *What might improve the instruments that are used to observe the Earth's environment from space?*

Certain thermal detectors on satellites can monitor the Earth's seasons and climates, but the space environment can degrade detector performance, thus resulting in faulty data.

- *How does space affect living things over time?*

To live and work in space, we have to understand its effects on life. LDEF carried living organisms, including biomolecules, plants, and tomato seeds that were used in recent experiments in schools across the Nation.

- *What can matter from space tell us about the universe?*

LDEF experiments sampled cosmic dust, interstellar gases, subatomic radiation particles, and the dust of comets.

LDEF's Deployment Into Space

Just as LDEF was built to fit the Shuttle and complement its capabilities, LDEF's

deployment and retrieval schedules were repeatedly adjusted to fit the complexities of Shuttle scheduling.

The first Shuttle flight took place in April 1981. Later that year, LDEF was removed from storage, and preparations began for a target launch date initially set for December 1983. Pre-flight structural tests of the satellite were conducted at Langley in 1982. With the Shuttle operational, Johnson Space

Center in Houston was able to provide analyses to predict the flight loads that LDEF would have to handle.

In June 1983, inside a special air-conditioned container, LDEF was shipped aboard a World War II era landing craft to KSC in Florida, where it was placed in SAEF-2, the Spacecraft Assembly and Encapsulation Facility.

Launch was set for April 1984. In November 1983, LDEF project participants from Langley moved to KSC to conduct pre-launch preparations. Experiments had to be received, processed, and fastened into place aboard LDEF.

With its experiments aboard, LDEF then had to be taken through the elaborate pre-launch processing for a Shuttle payload. At KSC's Operations and Checkout (O&C) Building, LDEF was placed into a payload canister for transfer to the launch pad, where it was integrated into Shuttle *Challenger's* cargo bay.

Challenger carried LDEF into space after lifting off from Pad A, Launch Complex 39, at 8:58 a.m. EST (eastern standard time) on April 6, 1984. This STS



LDEF, inside a special container, was shipped to Kennedy Space Center by water in June 1983.



Liftoff of Shuttle Challenger, April 6, 1984, with LDEF aboard

(Space Transportation System) 41C mission was the 11th Shuttle flight.

On *Challenger's* 19th orbit, at a point above the Pacific Ocean near Wake Island, LDEF was deployed at 12:26 p.m. EST on April 7. The orbit was nearly circular at 257 nautical miles and at an inclination to Earth of 28.4 degrees. Everything went as planned.

Relative to Earth, the Shuttle was on its back, at an angle, tail end down during the deployment operation. Relative to its orbit path, *Challenger* was facing rearward. Astronaut Terry Hart used the Shuttle's 50-foot-long remote manipulator arm to engage LDEF and move

it out of the payload bay. In the process, a startup signal was sent to electrical systems in the experiments. The space age had never before known a satellite designed to be orbited, brought back to Earth, and used again.

To move away from LDEF, the Shuttle fired small thrusters, causing the relative motion of the two separating spacecraft to change. The separation rate at first was about 1/2 foot per second, and it was raised incrementally to about 5 feet per second.

After leaving LDEF, *Challenger* went on to successfully carry out STS-41C's other main purpose of catching and repairing the Solar Maximum Mission satellite (Solar Max). Solar Max, launched in 1980 with instruments to study the Sun, began to

fail after 10 months of operating as planned.

Challenger returned to Earth on April 13, landing at Edwards Air Force Base, California, to end its nearly 7-day mission.

Plans at the time of deployment called for *Challenger* to retrieve LDEF in early February 1985. Later, the schedule was slipped to the fall of 1986 to accommodate other Shuttle scheduling considerations. After *Challenger* was lost in January 1986, all Shuttle launches were suspended, and they did not resume until September 1988.

Treasure Trove of Data

LDEF was to remain in orbit for nearly 6 years. Overall, the much-

lengthened stay in space actually increased LDEF's technological and scientific value, although it was disadvantageous for some experiments. LDEF's fundamental task, after all, was to gather data on the effects of long-term space exposure. When the satellite was brought back to Earth in early 1990, it had become a treasure trove of information.

Retrieval was some distance in the future when Langley LDEF staff at KSC finished their post-launch work and headed back to Hampton. LDEF's specially configured, wheeled transporter and the experiment shipping containers were put in storage at KSC. Other equipment was sent back to Langley to be saved for post-flight use.

During the mid-1980's, with LDEF in orbit, extensive conceptual planning took place for additional LDEF missions that could re-use LDEF or use a variant of the original LDEF design. LDEF itself, once retrieved, could be varied in length simply by unbolting and replacing its longerons (the longitudinal members in the checkerboard grid) with shorter or longer ones. By September 1985, 42 companies, including 21 with experiments aboard LDEF, had expressed an interest in commercial experiments aboard a future LDEF.

The Shuttle program and therefore LDEF remained on hold through 1987 and into 1988. However, by early 1988, a possibility had arisen that the Sun might endanger LDEF's orbit.



LDEF in orbit with its 57 space-exposure experiments

Solar activity, which goes through cycles of about 11 years, was showing signs it might approach the maximum of past cycles. Increased solar activity would mean increased heating of Earth's outer atmosphere, expanding it and creating more drag for LDEF, which was orbiting in the atmosphere's uppermost reaches. This increased drag would mean a decaying orbit and the prospect of LDEF falling back to Earth in a fiery reentry before a Shuttle could retrieve it.

Unfortunately, solar activity predictions were rough at best. With the resumption of Shuttle operations, LDEF retrieval planning proceeded, factoring in monthly assessments from a panel of experts on solar activity. Radar continued to track LDEF's slowly diminishing altitude through 1989 and into

January 1990, when the LDEF retrieval mission (STS-32) ultimately took place.

In a complex balancing act, Shuttle planners had for over 1 year continually weighed the LDEF retrieval as one among many important considerations. For a number of reasons, retrieval launch dates had slipped from July to November to December, before Space Shuttle *Columbia* left Earth on January 9 to bring LDEF home.

On the morning of January 12, *Columbia* approached LDEF, passed below it, then circled in front of it to a point 400 feet above the satellite. *Columbia*'s Shuttle payload bay was open and facing Earth, with the remote manipulator arm extended toward LDEF in anticipation of grappling it—which occurred when the gap between the two spacecraft had been narrowed to 35 feet.

This method of approaching LDEF was important for preserving the quality of the satellite's space-

exposure data. In fact, the "R-bar" approach set the tone for all that was to come in the handling of the treasure trove of information.

It had long been recognized that in an approach similar to those used in spacecraft-rendezvous operations, the plumes of the Shuttle's maneuvering jets could contaminate LDEF's pristine data. As early as 1978, studies at Langley had suggested the R-bar approach as a way to preclude plume impingement on the open surfaces of the experiments.

When Mission Specialist Bonnie Dunbar grappled LDEF at 9:16 a.m. CST (central standard time) on January 12, the space-environment effects recorded on its experiment surfaces included minimized contamination from *Columbia*.

What followed was the first of many meticulous steps taken to preserve the integrity of the experiment data. For 4 1/2 hours, Dunbar used the remote manipulator arm to turn and maneuver LDEF for an extensive visual inspection and photographic survey of all its surfaces. In this way, any non-space effects caused during LDEF's descent to Earth in *Columbia's* payload bay could be distinguished from the effects meant for study.

After the photos were all taken, Dunbar berthed LDEF aboard *Columbia*. A few days later, on January 20, *Columbia* touched down at Edwards Air Force Base, California. With LDEF aboard, total Shuttle weight was 115 tons, or 5 tons heavier than any previous Shuttle at landing. The concrete runway had been chosen over the often-used dry lake bed at Edwards for better landing control of the heavily laden Shuttle.

Returning Experiments

Meticulous care to preserve the integrity of experiment data was a defining feature not only in bringing LDEF home, but also in bringing the experiments back to their investigators.

For other Shuttle missions, it was the "prelaunch processing" of payloads that required great attention and effort. In fact, for the retrieval mission itself, preflight payload work had included

Artist's concept of Space Shuttle Columbia retrieving LDEF



preparing a Navy communications satellite for Shuttle *Columbia* to launch. But *Columbia* was also to come back from space with LDEF and its 57 experiments, and that meant a new kind of payload concern: postlaunch processing.

With LDEF still inside, *Columbia* was ferried from Edwards to KSC atop an aircraft specially configured for that purpose. Special equipment to help ensure the cleanliness of the atmosphere inside the payload bay had been staged at stops along the way. If the ferry flight had been delayed for any reason, this equipment would have helped continue protecting the experiments from even slight contamination.

A team of LDEF project staff from Langley had arrived at KSC weeks before LDEF's return. Their job was to support the initial stages of postlaunch processing the returning LDEF payload. An international team, including scientists, engineers, technicians, and others, later assumed responsibility for inspecting and photo-documenting the experiments, for seeing to the contamination-free removal of the experiments from LDEF and their return to their investigators' home institutions, and for scrutinizing LDEF itself for information about the space environment.

Columbia arrived at KSC on January 26. A few days later, in KSC's Orbiter Processing Facility, LDEF was lifted out of the payload bay, placed in a special canister, and moved to the Operations and Checkout Building. On February 1, LDEF was placed on its own transporter and turned over to the Langley team. The next day it was moved to SAEF-2, the Spacecraft Assembly and Encapsulation Facility.

In the pristine cleanliness of SAEF-2, LDEF was set up, leveled, and readied to be rotated for access to each individual row of trays. Close inspection and other deintegration preparations took until February 22. During that time, experimenters could examine but not touch their experiments. Special clothing was required for work in the ultra-clean environment in which tray deintegration was about to begin.

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An experiment tray is removed from LDEF in S-157-2 at the Kennedy Space Center.

During deintegration, photo-documentation efforts were intensified. From the time *Columbia* had first grappled LDEF, a photographic record of the sometimes fragile surface conditions of the experiments had been compiled. After the individual trays were removed from the satellite, photographs were taken of all sides of the trays. An area with optimized lighting was set aside and used as a photographic studio.

By March 29, the last tray had been removed, closely inspected by the principal investigators, individually photo-documented, packed, and shipped to its home institution for comprehensive data analysis.

Each tray had been processed through a lengthy checklist of steps. The master schedule for this processing had been continually updated to accommodate the differing time demands for different trays at different stages. This allowed LDEF's monopoly on a portion of KSC's facilities to be kept as brief as possible, and it expedited attainment of the project's goal: the fruitful analysis of LDEF data.

Compared with the originally planned year in orbit, the 5-year, 9-month flight had greatly enhanced the potential value of most LDEF materials, systems, and experiments—especially the comparisons of findings on different areas of the spacecraft. NASA recognized this potential and created four LDEF

SIG's (Special Investigative Groups) to address it. The SIG's will provide a unified perspective for spacecraft regarding materials, systems (e.g., seals, fasteners, mechanisms, and canisters), radiation, meteoroids and debris, and contamination.

By March 29, the SIG's had begun this expanded analysis of the LDEF structure and experiment trays so that the combined value of LDEF data to space missions would be assessed and documented.

Even after the trays were gone, the extra-long working days for the Langley LDEF deintegration team continued, lasting through April and into May. LDEF itself needed the same sort of attention that the experiments were going to receive because it too was an experiment. What better way to understand long-duration space-exposure effects on a spacecraft than to bring one home for scrutiny after a long stay in space? The close look at LDEF included a broad range of study from the meteoroid and debris survey of the entire structure to the evaluation of the welds in the center ring frame.

By mid-May, LDEF and its transporter had been stored at KSC, the Langley LDEF team and its equipment were returning to Hampton, and experiment data analysis was well under way at numerous locations around the United States and the world.

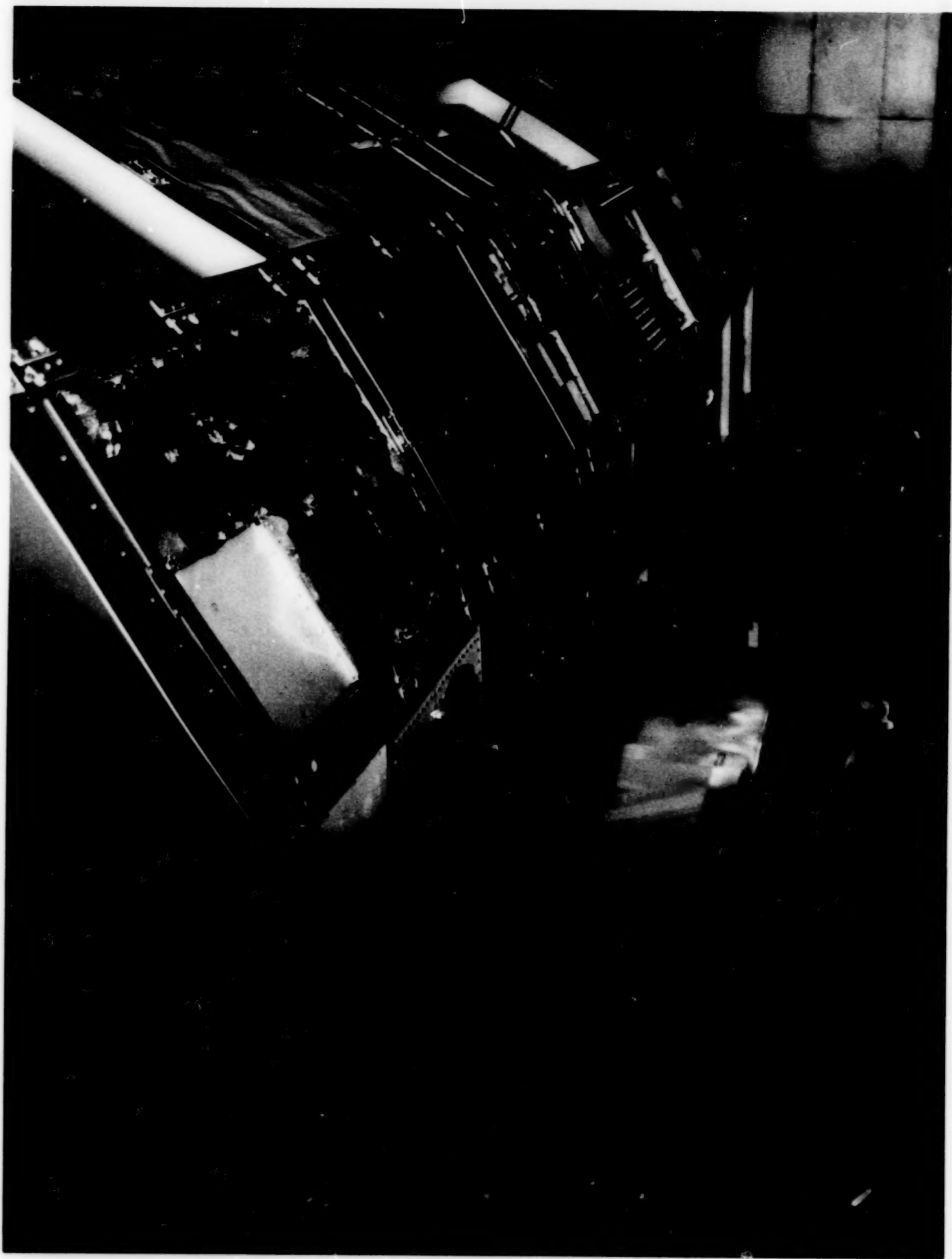
LDEF
Chronology

- LDEF is the direct forerunner of LDEF, called Meteoroid and Orbital Debris Experiment (MODE), to be first Shuttle payload
- LDEF project formally under way, managed by Langley for NASA's Office of Aeronautics and Space Technology (OAST)
- LDEF structure designed and fabricated at Langley
- October 1981** LDEF preparations under way for December 1983 target launch date
- September 1981** First international meeting of LDEF experimenters held at Langley
- 1982** LDEF structure tested for ability to withstand Shuttle-induced loads
- June 1983** LDEF shipped from Langley to KSC; placed in SAEF-2 (Spacecraft Assembly and Encapsulation Facility)
- April 7, 1984** During STS mission 41-C, at 12:26 p.m. EST, Shuttle *Challenger* places LDEF in nearly circular orbit of 257 miles high
- March 1985** Planned LDEF retrieval (via STS 51D) deferred to later Shuttle flight
- January 1986** LDEF's stay in space extended indefinitely when all Shuttle operations suspended because of the loss of *Challenger*
- September 7/1986** Shuttle operations intensify efforts to accelerate recovery of LDEF and return of Shuttle to flight
- June 1988** LDEF is moved from its stowage bay on *Challenger*, set for December 1988 retrieval by Shuttle *Columbia*
- December 18, 1988** STS-32 launched, scheduled until second week of January
- January 1990** STS-32 launched January 9, LDEF retrieved 9:16 a.m. CST January 12; *Columbia* landed at Edwards Air Force Base, California, January 20
- January 26, 1990** *Columbia*, with LDEF still in payload bay, returned to KSC via ferry flight from Edwards Air Force Base
- January 30 to February 31, 1990** LDEF removed from *Columbia* in KSC's Orbiter Processing Facility, placed in a special payload container, and transported to Operations and Checkout Building
- February 1 and 2, 1990** LDEF placed in special transporter, the LDEF Assembly and Transportation System (LATS), and moved to SAEF-2 for experiment de-integration
- February 5 to 23, 1990** Deintegration and preparation activities take place, including extensive inspection and photo-documentation
- February 23 to March 1, 1990** Tray contents are inspected, individually photo-documented, packed, and sent to various institutions for comprehensive data analysis
- April and May, 1990** Deintegration wrap-up, including comprehensive investigation and photo-documentation of the LDEF structure itself

LDEF Fact Sheet

- Mission** Long-term study to define the space environment and to investigate the effects of this environment on space operations.
- Satellite structure**
- Reusable, open-grid, 12-sided (plus 2 ends)
 - Designed and built (mainly 6061-T6 aluminum) at NASA Langley Research Center
- Dimensions & weight**
- 30 feet long, 14 feet in diameter
 - 8400 pounds empty
 - 21,400 pounds with 86 trays holding 57 experiments
- Flight data**
- Deployment mission: STS-41C launched April 6, 1984, Shuttle *Challenger*
 - LDEF deployed into orbit April 7, 1984
 - Orbit altitude near circular at 257 miles; orbit inclination 28.4 degrees
 - LDEF total distance traveled: 741,928,837 nautical miles, or 32,422 orbits
 - Recovery mission: STS-32 launched January 9, 1990, Shuttle *Columbia*
 - Retrieved from orbit January 12, 1990
 - Landed at Edwards Air Force Base, California, January 20, 1990
- Experimental method and apparatus**
- Long-term exposure of passive and active test specimens
 - Preparation at individual investigators' home institutions
 - Post-flight data analysis at home institutions
 - Low or no power demands
 - Minimal or no data recording requirements
 - Leave and retrieve (no data transmitted from orbit)
- Technology, applications, and science experiment categories**
- Materials, coatings, and thermal systems
 - Power and propulsion
 - Electronics and optics
 - Basic science
- Environment for experiments**
- Free-flying in low Earth orbit
 - Gravity-gradient stabilized (unchanging orientation)
 - Passive spacecraft with lowest contamination levels and acceleration forces to date
 - Controlled environment pre-deployment and post-retrieval
- Experiment trays**
- 86 total trays: 72 peripheral (12 sides at 6 per side) and 14 end (6 facing Earth, 8 facing away from Earth)
 - Approximate dimensions 3 x 4 feet (peripheral); 2.5 x 2.5 feet (end)
 - Depth 3, 6, or 12 inches
 - Aluminum construction; capacity up to 200 pounds
- Affiliations:**
- More than 200 experiment principal investigators from
 - 33 private companies
 - 21 universities
 - 7 NASA centers
 - 9 Department of Defense laboratories
 - 8 foreign countries
 - More than 100 other investigators from around the world involved in Special Investigation Groups (SIG's)

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